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On the Possibility that Supernovas Influence Homochiral Organic Molecule Formation

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Abstract

The origin of the homochirality of the organic molecules in living material remains a mystery. We propose here that the supernova(s) that initiated the solar system also produced the mechanism for the chiral symmetry breaking in the organic material in the interstellar medium. The major process would involve either $\bar{\nu}_e$ from a supernova explosion or the $A\ell^{26}$ produced in the debris in conjunction with the weak neutral current process. Both give rise to chiral positrons and interactions with the organic material in the prebiotic medium. We describe some possible tests of this concept. We note that in this picture, all life forms in the Universe based on hydrocarbons should have the same chiral structure.

1 Introduction

There is increasing evidence that the formation of the solar system was initiated by one or more nearby supernovas. This evidence is obtained largely from the isotopes found in pre-solar grains in old meteorites and from dynamical models of the formation of stars and planetary systems. In this paper, we address the question of the origin of a homochiral prebiotic organic medium in connection with supernova emissions. We find that most of the emission ($\bar{\nu}_e, A\ell^{26}$) would provide a mechanism for selectively inducing a homochiral structure in the organic materials in the interstellar medium (ISM) and elsewhere.

For more than a century, there has been evidence for the chiral nature of life forms on earth. Pasteur was among the first to point this out (1848-

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1880), and the universal nature of chiral symmetry breaking in DNA and RNA is now very well established for all life forms. With the discovery of parity violation in charged current reactions in 1956 and of the weak neutral current (WNC) in 1973, two universal symmetry-breaking processes (WNC and β-decay) were uncovered that could have effected the handedness of DNA and RNA. The main problem is the extremely small symmetry-breaking effects ($\Delta E/k_B T \sim 10^{-17}$). There are, however, plausible non-linear mechanisms that could have amplified this small symmetry-breaking phase transition up to the full symmetry-breaking level observed in life forms. However, there is a long-standing controversy as to whether these non-linear effects are actually large enough to have determined the selection of the handedness of life [1–11].

Recently there has been increasing interest in the chiral nature or handedness of biomolecules. In fact there are some who claim that the complex biomolecular structure of life must have arisen from a "chiral pure" medium [12, 13]. This concept, combined with the likelihood that the period on Earth for life to have originated seems to be sometime between 3.8 and 3.5 billion years ago, leaves a small window of 300 million years or less for life to have emerged from the prebiotic medium. Indeed, some speculate the time could be less than 10 million years.

In this paper, we discuss the possible effects of a chiral impulse that could have come from the intense pulse of neutrinos or radioactive debris interaction from a very close supernova explosion or a sudden release of a large amount of radioactive material near Earth to aid in the formation of a chirally pure "prebiotic"medium for the origin of life [14].

2 Chiral Symmetry Breaking and Bifurcation

In contrast to the gradual build up of symmetry breaking, we propose here another mechanism resulting from the effects of a nearby supernova or an impulse of β-emitters ($A\ell^{26}$). Initially this might seem to be an unimportant effect that has been ignored in the past literature on this subject but, with increasing interest currently, more attention should be paid to this issue. Here we present some results based on our previous work [8, 14]. We believe it is most likely that this interaction occurred in the ISM where organic-loaded dust particles helped form the enormous cloud that subsequently formed the solar system.

To simulate this intense pulse interaction combined with some reasonable condition, we added a time-dependent quasi δ-pulse, which gives very large, but not infinite, amplitude to the small bias g. We are assuming that both the WNC and the impulse of chiral symmetry-breaking effects occurred. Then the first-order stochastic equation [1, 8]

$$\frac{d\alpha}{dt} = -A\alpha^3 + B(\lambda - \lambda_c)\alpha + \epsilon^{1/2} f(t) + Cg \quad , \tag{1}$$

becomes

$$\frac{d\alpha}{dt} = -A\alpha^3 + B(\lambda - \lambda_c)\alpha + \epsilon^{1/2} f(t) + Cg + d\delta_{\lambda\lambda'} \quad , \tag{2}$$

where α is the amplitude of the symmetry-breaking solution, λ the control parameter, λ_c the symmetry-breaking transition (critical) point, $\epsilon^{1/2}$ is the rms value of fluctuation (noise), $f(t)$ is the normalized fluctuation (noise), g is the interaction or bias symmetry-breaking selector, d is the amplitude of a quasi δ-pulse, and $\delta_{\lambda\lambda'}$ is the δ-function which gives $\delta_{\lambda\lambda'} = 1$ when $\lambda = \lambda'$ and $\delta_{\lambda\lambda'} = 0$ when $\lambda \neq \lambda'$. Therefore,

$$\lambda = \lambda_c + \gamma t \quad , \tag{3}$$

where λ_c is the initial value of λ, γ the evolution rate, and t the evolution time.

To solve the first-order stochastic equation numerically, we designated the initial symmetry-breaking amplitude, α, as zero at time $t = 0$, but the $f(t)$ is a random number generated by computer within [-1, 1]. To obtain the trace of α at a different time for each trial, we just sampled it at different times. (Our studies confirm the results of Kondepudi and Nelson [1].) One simulation assumes that the impulse takes place near and after the critical point ($\lambda_c = 1.0$) at $\lambda = 1.5$, and $\delta = d/g = 100$ is shown in Fig. 1. In this case, the impulse plays a dominant role to push the process toward a favored state! We have studied over 40,000 trials and find a trend that the early chiral impulse produces a significant bias towards the preferred state. Furthermore, we found an 80% probability of the favored state being selected [8, 15]. This illustrates the effect of a small symmetry-breaking process on a slowly evolving system. In essence, the small bias is magnified by the process of signal averaging, where the noise effect essentially cancels out. This process is sometimes called the Kondepudi effect [1]. Over a very long

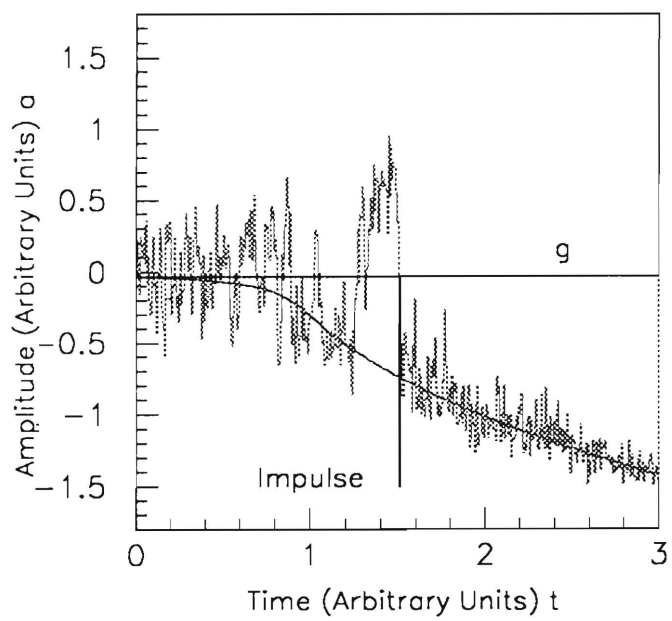

Figure 1: Single trial with an impulse at $\lambda = 1.5$ where $\delta/g = 100$. The impulse strongly affects the phase transition.

period preceding the formation of the solar system, there could have been many supernovas generating both $\bar{\nu}_e$ and $A\ell^{26}$ "impulses" into the organic medium, as shown schematically in Fig. 2. The β^+ from the $A\ell^{26}$ could cause an asymmetry in the interaction with the organic molecules.

3 Source of the Chiral Impulse

There are three effects from a Type-II supernova in the primordial cloud that may have formed the solar system [16]:

1. $\bar{\nu}_e$ emission (with $\bar{\nu}_e + p \rightarrow e^+ + n$ interaction in the hydrocarbon),
2. ν_e, $\bar{\nu}_e$, ν_x, $\bar{\nu}_x$ ($x = \mu, \tau$) neutrino emission and subsequent coherent interaction with the nuclei of the organic materials,
3. Intense β emittances like $A\ell^{26}$ formed by supernovas that emit polarized e^+ particles that interact with the organic materials.

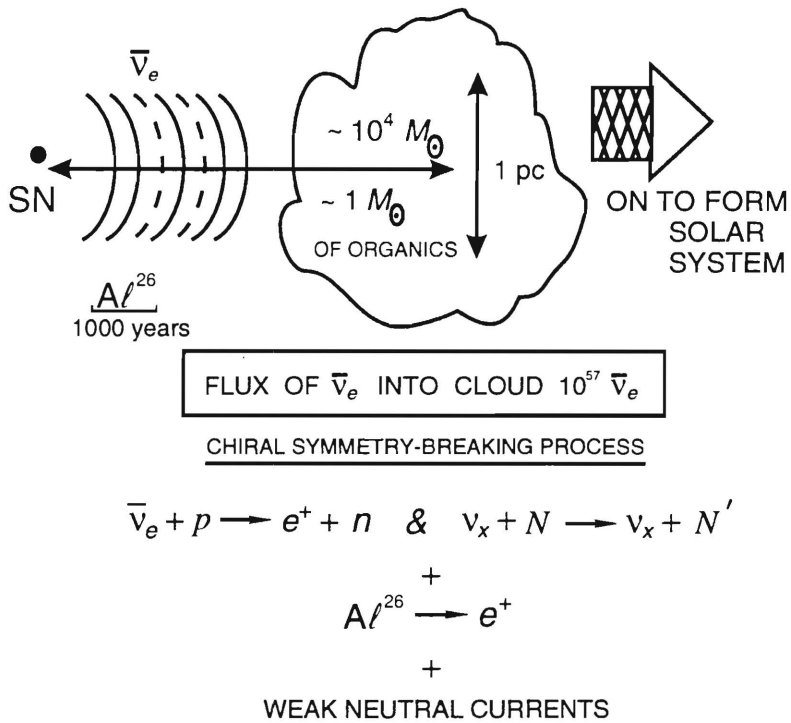

Figure 2: Schematic effect of a Type-II supernova on the organic molecules in a dense molecular cloud (possibly one that went on to participate in the formation of the solar system). This could have produced an intense chiral impulse.

Of course, all this time the effect of the WNC can be driving the system towards a homochiral state, as depicted in Eqs. (1) and (2).

Let us consider the rate of these effects:

1. For $\bar{\nu}_e$ absorption and a supernova 1 parsec away (or inside a 1-pc dense cloud), the number of interactions will be $\sim 10^4$/kg of material for 1.0 $M_\odot$ of organic material (which would be 6×10^{34} interactions in the organic matter that is *active*); therefore, the positrons from the $\bar{\nu}_e$ interactions would lose energy at a rate of 10^{-19} MeV/cm and thus travel nearly a parsec. An asymmetry of 10^{-17} could be amplified in this situation.

2. For the coherent $\nu_x + N \rightarrow \nu_x + N$, and for the carbon in the hydrocarbons, we would have $\sim 10^2$ more or 6×10^{36} interactions in the organic material.

3. For the $A\ell^{26}$ over the half life, there would be $\sim 10^{50}$ decays producing $\sim 10^{50}$ positrons that lose energy at the rate of 10^{-19} MeV/cm; for MeV positrons, the range of the positrons would be of order of a parsec (ignoring possible magnetic-field effects).

Consider the example where 0.001 $M_\odot$ of $A\ell^{26}$ is produced and assume, for simplicity, that the energy of the e^+ is 1 MeV and is contained in the gas cloud. Assume the cloud has a density of 10^4 atoms/cm^3 and that 10^{-3} of the atoms are organic, the stopping power for e^+ will be

$$\frac{dE}{dx} \sim \text{MeV/g/cm}^3 \quad , \tag{4}$$

and for a density of $\rho = 10^4$ atoms/cm $^3 \sim 10^{-19}$ g/cm^3 we find,

$$dx \simeq \frac{dE}{\rho}(\text{MeV}) \sim 10^{19} \text{ cm } (\sim 3 \text{ ps}) \tag{5}$$

(we neglect radiation ρ processes and magnetic fields), and for an average energy exchange of 10 eV, we have

$$\frac{10^5_e \text{ collisions}}{A\ell^{26} \text{ decay}} \quad . \tag{6}$$

For 0.001 $M_\odot$ of $A\ell^{26}$ and 10^{-3} organic fraction, we obtain a total of $\sim 10^{55}$ collisions of polarized positrons with organic materials in the cloud assuming all of the e^+ stop in the cloud. (We assume that only one of the collisions can result in spin exchanges.) There will also be the same order of polarized photons from the $e^+e^- \rightarrow \gamma\gamma$ annihilation. It is estimated in Refs. [14, 17] that the asymmetry due to the weak interaction would be of order 10^{-11} to 10^{-6}, depending on the positron energy {it scales like $\alpha^2[\alpha/(\nu/c)]^2$}. Thus it takes N $\sim 10^{22}$ interactions for the asymmetric to become statistically important. In this example there are far more interactions.

It is clear that the largest effect in all of these processes will be the result of the interaction of the polarized e^+. It is plausible that these e^+ give rise to a reasonable fraction of chiral interactions and, thus, classify as a chiral impulse, as shown schematically in Fig. 1.

4 Conclusions

The combined effect of the WNC in the organic material in a primordial gas cloud and a nearby supernova explosion, which gives rise to the different interactions described here, could give appreciable chiral symmetry breaking.

Experimental measurements of the effects of chiral (polarized) electrons and $\bar{\nu}_e$ (from a reaction, for example) could give input to a model calculation of the onset of homochirality in organic materials.

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